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基于*NDVI*的新疆荒漠地区植被覆盖度遥感估算经验模型研究①

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摘　要: 新疆荒漠地区植被覆盖度遥感估算模型十分缺乏,给荒漠化监测等相关工作带来很大不便,开展植被覆盖度遥感估算经验模型研究,对于促进和完善相关地区的生态监测及研究工作具有积极的现实意义。通过对阜康市北部沙漠南缘和克拉玛依市中部平原荒漠进行无人机航拍,利用无人机遥感提取(光合)植被信息,并将无人机航拍影像的植被覆盖度统计单元与高分辨率卫星影像像元在空间上直接相对应,获取在高分辨率卫星影像像元尺度上的植被盖度,然后通过植被覆盖度和空间上与其相对应的源自高分辨率卫星影像的*NDVI*数据的拟合关系,建立基于源自高分二号影像的*NDVI*的阜康北部沙漠植被覆盖度遥感估算线性模型以及基于源自ZY1-02C影像的*NDVI*的克拉玛依平原荒漠植被覆盖度遥感估算二次多项式模型。研究中所采用的无人机遥感与卫星遥感相结合、植被覆盖度统计单元与卫星像元在空间上直接对应的方法,可避免以往相关工作中常以点位测量数据代表卫星像元数据所带来的不确定性。由于所用卫星影像的*NDVI*数据稳定性相对不足等原因,所建立的遥感估算模型的估算精度尚相对偏低,有待于今后进一步的工作加以改进。

关 键 词: *NDVI*; 荒漠; 植被覆盖度; 遥感估算; 经验模型

植被覆盖度是观测区域内植被垂直投影面积占地表面积的百分比,是刻画陆地表面植被数量的一个重要参数,也是指示生态系统变化的重要指标。在土地利用/土地覆盖变化以及生态环境变化监测研究中,植被覆盖度的应用十分普遍。

传统的植被覆盖度数据可以通过地面实测获得,但是其获取过程费时、费力,在现代生态环境监测与研究中,尤其在监测或研究大面积区域时,单纯依靠地面实测已难以满足需求。因此,利用遥感手段间接获取植被覆盖度数据的方法应运而生,人们也探索出了基于植被指数的估算方法(如经验模型法)、基于数据挖掘技术的估算方法(如决策树分类法)等多种估算方法[1]。由于植被指数与植被覆盖度具有很强的线性或非线性相关性[2-3],因此,多年来植被指数在植被覆盖度遥感估算中的应用十分普遍,其中,又以归一化植被指数(*NDVI*)应用最为广泛[4-16]。

受多种因素限制,现有利用遥感手段估算植被覆盖度的方法一般均各有优缺点。以目前国内应用较为流行的像元分解模型为例,由于模型中需要有全植被覆盖的像元,这就限制了该模型对低分辨率遥感数据的使用[5],也限制了模型在一些植被覆盖度总体偏低地区例如西北干旱荒漠地区的应用。相对而言,经验模型法(或称回归模型法)虽然也有局限性,一般只适用于特定的区域与特定的植被类型[5],但该模型原理相对简单、容易实现、精度较高,应用上也较多数其它估算方法简便。国内目前关于干旱区的相关经验模型还不多[6,17],新疆地区虽有学者对植被覆盖度的遥感估算方法开展过一些工作[18-22],但经验模型则尚仅见于有学者在石河子

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地区所做的非专门针对荒漠地区的工作[18]。开展新疆荒漠地区植被覆盖度遥感估算经验模型的研究,对于促进和完善相关地区的生态监测及研究具有积极的现实意义。

已有的研究在调查或估算植被覆盖度时多是单独应用地面实测、无人机遥感[17,23-30]或是卫星遥感。也有部分研究是将地面实测与卫星遥感相结合,但在将地面实测与卫星遥感结合时,一般是以点位测量数据(单个样方值或多个样方平均值)代表大尺度卫星影像像元数据[18],植被覆盖度与卫星影像像元的空间对应关系并不直接,存在着一定的不确定性。本文拟通过将无人机遥感与卫星遥感相结合,先采用超低空无人机遥感提取植被信息,再将无人机航拍影像所提取的植被覆盖度与卫星影像像元在空间上直接相对应起来,在此基础上,探索建立基于 *NDVI* 的新疆荒漠地区(光合)植被覆盖度[31]卫星遥感估算经验模型。

1 数据处理与研究方法

1.1 工作步骤

研究工作分为 5 个步骤:(1) 选择天气晴好的日期对研究区进行无人机超低空航拍。(2) 根据航拍影像,提取所摄区域的植被信息。(3) 购买于航拍当日过境的米级或亚米级高分辨率卫星影像,计算其 *NDVI*。(4) 将航拍影像与卫星影像配准后,以源自卫星影像的 *NDVI* 的格元为统计单元,计算航拍影像植被覆盖度。(5) 根据航拍影像植被覆盖度和空间上与其一一对应的 *NDVI* 的数据拟合情形,建立二者的经验关系模型。

1.2 数据采集

选择阜康市北部的古尔班通古特沙漠南缘和克拉玛依市中部平原荒漠作为航拍区,分别位于地理坐标 87°57′39.6″E、44°22′19.2″N 和 85°5′5.7″E、45°33′0″N 附近(图 1)。航拍采用大疆悟 1 pro 四轴飞行器进行,单块电池飞行时间约 15min,相机镜头分辨率为 1 600 × 10^4 像素。航拍分别于 2017 年 6 月 20 日和 2016 年 9 月 3 日进行,拍摄之前两日及拍摄当日天气晴或多云,静风至微风,地表干燥。拍摄时镜头垂直向下,航向和旁向重叠度均保持在 70% 以上,航高约 6 ~ 7 m,照片地面分辨率约 0.002 ~ 0.003 m。阜康航拍区由相距约 40 m 的两块区域组成,共拍摄照片 1 976 幅,涉及面积约 0.518 hm^2;克拉玛依航拍区共拍摄照片 1 553 幅,涉及面积约 0.68 hm^2。

航拍结束数月后经查询购买到 2017 年 6 月 20 日航拍当日过境阜康航拍区的高分二号卫星影像 (GF2 _ PMS2 _ E88. 0 _ N44. 5 _ 20170620 _ L1A0002431214),以及 2016年9月2日即航拍前

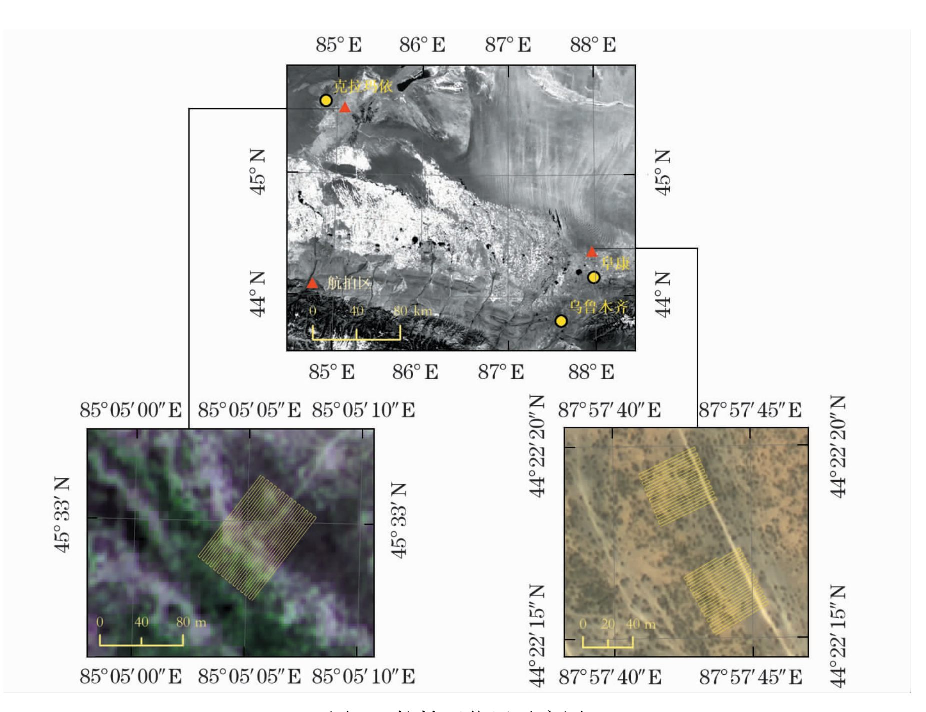


图 1 航拍区位置示意图

Fig. 1 Aerial shooting area

一日过境克拉玛依航拍区的 ZY1-02C 卫星影像(ZY02C_HRC_E85.2_N45.7_20160902_L1C0003517850、ZY02C_PMS_E85.2_N45.7_20160902_L1C0003517696),航拍区晴空无云。高分二号的全色波段影像分辨率为 1 m,多光谱影像分辨率为 4 m,ZY1-02C 的 PMS 相机全色波段影像分辨率为 5 m,多光谱影像分辨率为 10 m,HR 相机影像分辨率为 2.36 m。

1.3　数据处理

1.3.1　影像拼接与校正　航拍影像采用 Agisoft Photoscan 软件进行拼接处理,经对齐照片、建立密集点云、生成网格、生成纹理等步骤后,最终生成正射 RGB 影像。高分二号影像和 ZY1-02C 影像采用 ENVI 软件进行辐射定标、大气校正和正射校正(正射校正输出结果的采样方式为立方卷积),投影方式为 WGS_1984_UTM_Zone_45N。

分别根据高分二号的全色波段影像和 ZY1-02C 的 HR 影像对阜康航拍区和克拉玛依航拍区航拍正射影像进行配准。图像配准、切割及投影转换等工作在 ArcGIS 软件下进行。图像输出结果的采样方式均为最近邻,配准精度控制在 0.5 个像元之内。

1.3.2　植被信息提取　数码相机照相法是植被覆盖度地面测量法中最客观且精度最高的测量方法[32],本研究中采用的无人机超低空航拍其相对航高不足 8 m,本质上仍可看作是数码相机照相法的一种实施方式。已有研究表明,利用无人机替代人工开展荒漠地区植被覆盖度调查是相对客观、高效和值得推广的一种调查方式[17]。根据前人研究成果,可见光波段差异植被指数 *VDVI*(visible-band difference vegetation index)在植被和非植被分离度较高,其数值几乎没有交叉,比较适合无人机拍摄影像植被的提取[17],因此本文采用 *VDVI* 指数用于无人机 RGB 影像的植被信息提取。

VDVI 的计算公式为:

$$VDVI = \frac{2 \times \rho_{green} - \rho_{red} - \rho_{blue}}{2 \times \rho_{green} + \rho_{red} + \rho_{blue}} \tag{1}$$

式中:ρ_{red}、ρ_{green}、ρ_{blue}分别为红、绿、蓝 3 个波段对应的反射率。

由于无人机影像噪音的存在,*VDVI* 提取的植被信息一般会略多于实有的(光合)植被信息,但通过合理设置提取阈值,可以将这一误差控制在适当的范围内。结合目视解译以及航拍当日实地调查情形,经过反复比较尝试,选择 0.034 作为本研究中航拍影像的光合植被 *VDVI* 提取阈值(图 2)。对照实地调查结果可发现,在对应卫星影像的裸地或几无光合植被的像元(植被覆盖度视为 0),*VDVI* 据此阈值提取的无人机影像植被覆盖度均不超过 0.08%,这个误差对于荒漠区植被动态监测来说是完全可以接受的。

1.3.3　*NDVI* 生成、植被覆盖度计算及数据拟合　分别用红和近红外两个波段数据计算高分二号影像和 ZY1-02C 影像的 *NDVI*。使用 ArcGIS 软件中的 Zonal Statistics 工具,将由航拍影像提取的(光合)植被信息与 *NDVI* 图进行叠加,统计生成 *NDVI* 图像各对应格元内的植被覆盖度(图 3)。根据分别源自高分二号影像的 *NDVI*(以下简称 GF2-*NDVI*)和源自 ZY1-02C 影像的 *NDVI*(以下简称 ZY1-02C *NDVI*)与对应的无人机航拍影像提取的植被覆盖度信息的拟合情况,建立 *NDVI* 与植被覆盖度的经验关系模型,并根据优选出的关系模型,分别进行植被覆盖度计算,生成植被覆盖度图。数据系列关系拟合借助

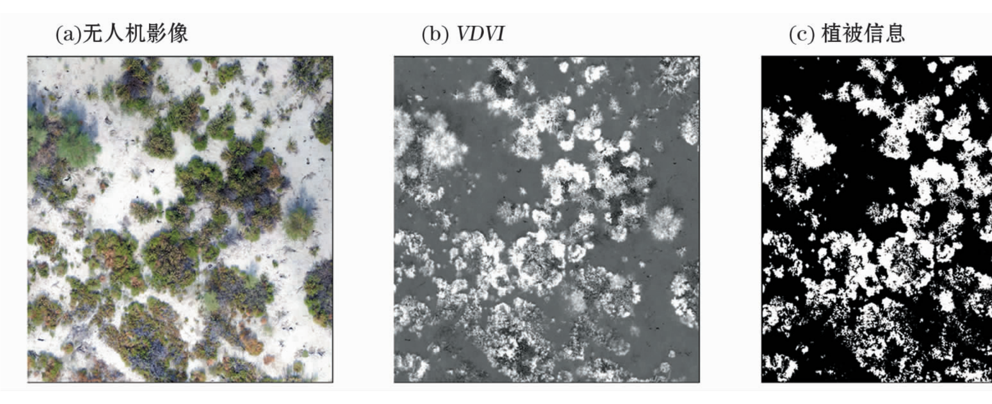


图 2　*VDVI* 提取植被信息效果

Fig. 2　Effect of extracting vegetation information from *VDVI*

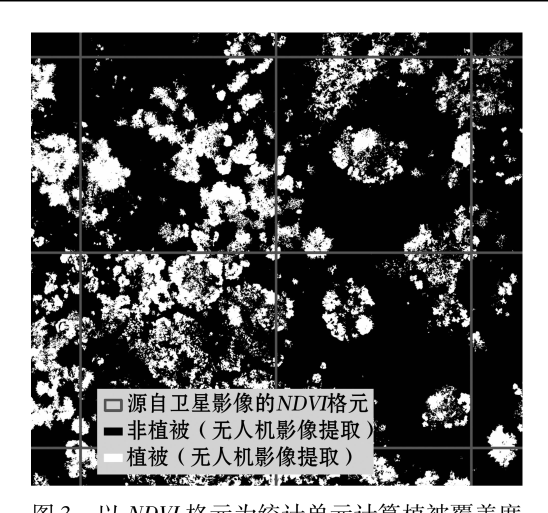


图3　以 *NDVI* 格元为统计单元计算植被覆盖度

Fig. 3　Computing vegetation coverage with *NDVI* cells as statistical units

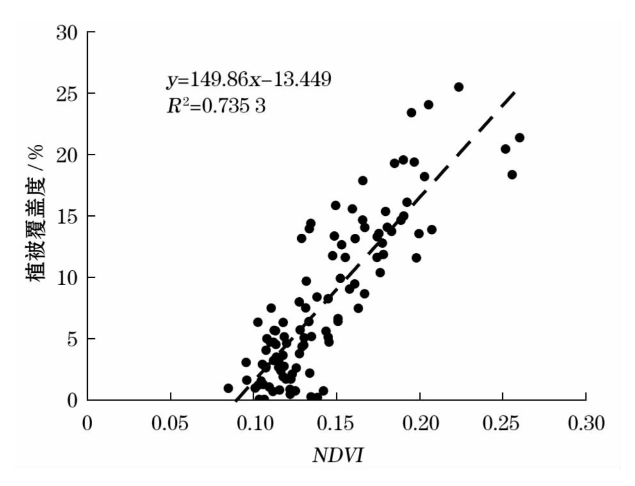


图4　GF2-*NDVI* 与植被覆盖度的拟合关系

Fig. 4　Fitting relation between GF2-*NDVI* and vegetation coverage

Origin 软件完成。

2　结果与分析

2.1　基于 GF2-*NDVI* 的阜康北部沙漠植被覆盖度遥感估算模型

将由航拍影像提取的(光合)植被信息与 GF2-*NDVI* 图进行叠加,统计 GF2-*NDVI* 图像各对应格元内的植被覆盖度,去除边缘不完全重叠格元,共提取107 对 GF2-*NDVI* 值及与该 GF2-*NDVI* 图像格元相对应的植被覆盖度数据,在 Origin 中进行拟合,结果表明,多项式拟合效果最好,线性次之(图4、表1)。多项式虽然随着次数增加,决定系数 R^2 的值也继续增大,但由于多项式高次项的系数为负值,随着 x 值(*NDVI*)增大,y 值(植被覆盖度)在30 附近或稍大于20 处即出现向下的拐点,显然与常识不符,因此,选取线性方程 $y = 149.86x - 13.449$ ($R^2 = 0.7353$)

表1　GF2-*NDVI* 与植被覆盖度的拟合方程

Tab. 1　Fitting equations of GF2-*NDVI* and vegetation coverage

趋势线类型	方程	决定系数 R^2
指数	$y = 0.203e^{22.291x}$	0.4442
线性	$y = 149.86x - 13.449$	0.7353
对数	$y = 22.929\ln(x) + 53.236$	0.7340
多项式	$y = -311.85x^2 + 251.03x - 21.138$	0.7424
幂	$y = 512.0x^{3.5206}$	0.4726

作为基于 *GF2-NDVI* 的阜康北部沙漠植被覆盖度遥感估算模型。据此模型计算的覆盖度如图5所示,与这一区域多中高盖度梭梭、总体以固定半固定沙漠为主的野外实况相符。

2.2　基于 ZY1-02C *NDVI* 的克拉玛依平原荒漠植被覆盖度遥感估算模型

与2.1 节类似,将由航拍影像提取的(光合)植被信息与 ZY1-02C *NDVI* 图进行叠加,统计 ZY1-02C

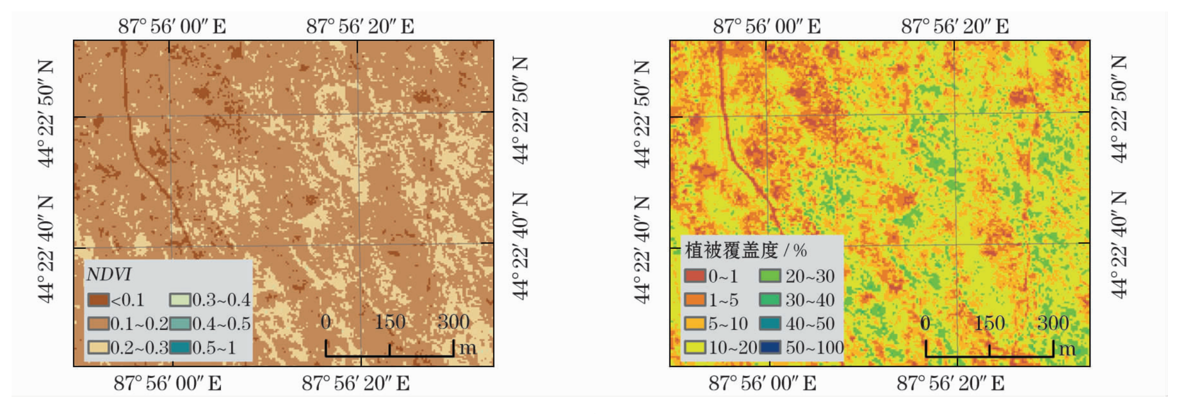


图5　GF2-*NDVI* 及其对应的植被覆盖度

Fig. 5　GF2-*NDVI* and its corresponding vegetation coverage

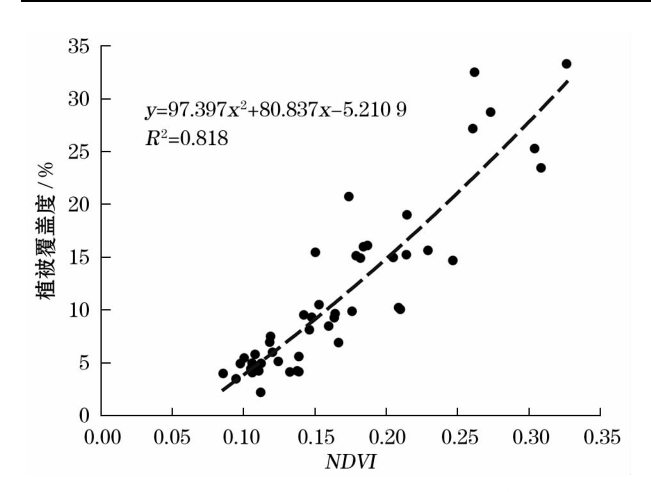


图 6　ZY1-02C *NDVI* 与植被覆盖度的拟合关系

Fig. 6　Fitting relation between ZY1-02C *NDVI* and vegetation coverage

表 2　ZY1-02C *NDVI* 与植被覆盖度的拟合方程

Tab. 2　Fitting equations of ZY1-02C *NDVI* and vegetation coverage

趋势线类型	方程	决定系数 R^2
指数	$y = 1.766\,5e^{9.793\,5x}$	0. 778 4
线性	$y = 118.9x - 8.499\,8$	0. 815 5
对数	$y = 20.468\ln(x) + 49.22$	0. 770 2
多项式	$y = 97.397x^2 + 80.837x - 5.210\,9$	0. 818 0
幂	$y = 236.74x^{1.763\,9}$	0. 804 8

NDVI 图像各对应格元内的植被覆盖度,去除边缘不完全重叠格元,共提取 47 对 ZY1-02C *NDVI* 值及与该 ZY1-02C *NDVI* 图像格元相对应的植被覆盖度数据,在 Origin 中进行拟合,结果表明,多项式拟合效果最好(图 6、表 2)。因此,选取多项式方程 $y = 97.397x^2 + 80.837x - 5.210\,9$($R^2 = 0.818$)作为基于 ZY1-02C *NDVI* 的植被覆盖度遥感估算模型。据此模型计算的覆盖度如图 7 所示,与野外调查时图内中部偏右南北向道路的西侧区域以中高盖度梭梭、柽柳及花花柴等植被为主、东侧以低盖度稀疏梭梭为主的实况相符。

2.3　模型估算精度

根据公式(2)、(3)[30],以由航拍影像提取的植被覆盖度作为基准,可以分别计算得到 GF2-*NDVI*、ZY1-02C *NDVI* 与植被覆盖度关系模型的均方根误差和估算精度。

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(fc - fc')^2}{n}} \qquad (2)$$

$$Ac = \left[1 - \frac{RMSE}{\overline{fc}}\right] \times 100\% \qquad (3)$$

式中:*RMSE* 为均方根误差;*fc* 为作为基准的植被覆盖度样本值;*fc'* 为植被覆盖度估算值;*n* 为样本数;*Ac* 为估算精度;$\overline{fc}$ 为作为基准的植被覆盖度样本的均值。

由表 3 看到,上述两个估算模型的估算精度尚相对偏低,尤其是基于 GF2-*NDVI* 的植被覆盖度估算模型。这可能主要跟 GF2-*NDVI* 与植被信息对应

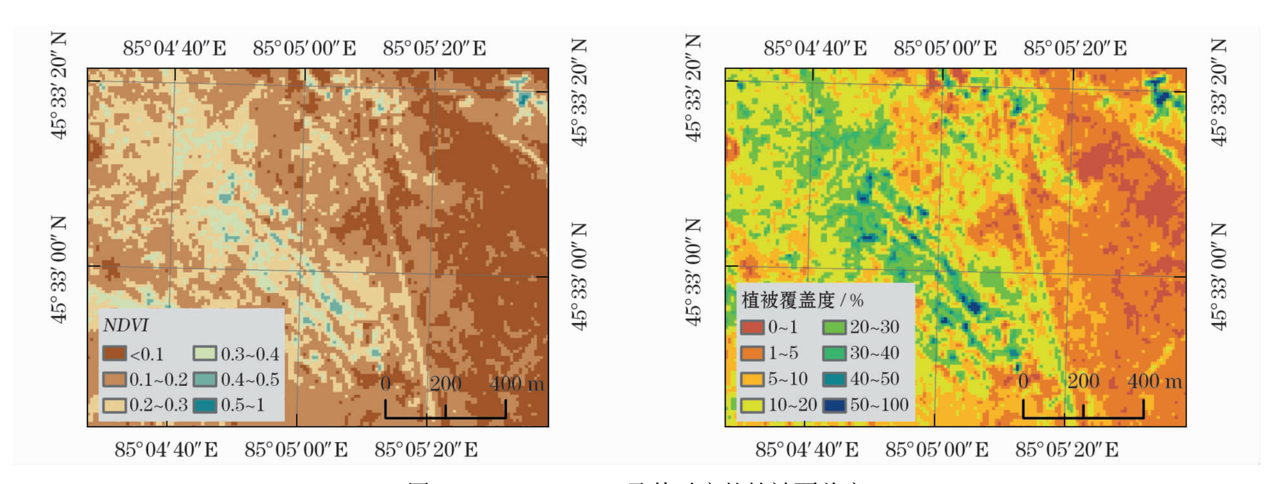


图 7　ZY1-02C *NDVI* 及其对应的植被覆盖度

Fig. 7　ZY1-02C *NDVI* and its corresponding vegetation coverage

表 3　模型的估算精度

Tab. 3　Accuracy of estimation models

模型	均方根误差(*RMSE*)/ %	估算精度/ %	模型	均方根误差(*RMSE*)/ %	估算精度/ %
GF2-*NDVI* 线性估算模型	3. 196 8	60. 31	ZY1-02C-*NDVI* 多项式估算模型	3. 412 0	70. 38

关系的稳定性相对不足有关。对照实地调查结果和GF2-*NDVI* 数据可以发现,在航拍区及其附近区域内,在裸地或仅有非光合植被的像元,GF2-*NDVI* 的值可在 0.028 ~ 0.135 之间变动,变动幅度明显偏大。此外,影像配准误差和植被信息 *VDVI* 指数提取误差也会有一定影响。

3 结 语

本文对探索基于 *NDVI* 的新疆荒漠地区植被覆盖度遥感估算经验模型做了一些尝试,取得了一些初步结果:

(1)通过无人机遥感与卫星遥感相结合、植被覆盖度统计单元与卫星影像像元直接对应的方法,可以使在构建植被覆盖度遥感估算模型过程中植被覆盖度与卫星影像像元的空间对应关系相对更为直观和准确,避免了以往相关工作中常以点位测量数据代表大尺度卫星像元数据所带来的不确定性,并为今后开展类似工作提供了一种思路。

(2)获得了基于源自高分二号影像的 *NDVI* 的阜康北部沙漠植被覆盖度遥感估算线性模型以及基于源自 ZY1-02C 影像的 *NDVI* 的克拉玛依平原荒漠植被覆盖度遥感估算二次多项式模型。这些模型可在一定程度上为新疆地区相关的生态监测和研究工作提供服务和参考。

由于本文所用卫星影像的 *NDVI* 数据稳定性相对不足等原因,所获得的遥感估算模型的估算精度尚相对偏低,有待于今后进一步的工作加以改进。

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Remote sensing estimation models for vegetation coverage in desert regions of Xinjiang based on *NDVI*

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Abstract: The lack of remote sensing estimation models in vegetation coverage for desert regions of Xinjiang, China has brought great inconvenience to desertification monitoring and other related work. It is of positive and practical significance to study the empirical models for remote sensing estimation of vegetation coverage for promoting and improving ecological monitoring abilities in relevant areas. In this study, unmanned aerial vehicle (UAV) photography was firstly carried out in typical desert regions in Xinjiang, vegetation information (photosynthesis) was extracted by UAV images. Secondly, vegetation coverage was obtained at the pixel scale of high resolution satellite image by making the statistical units of vegetation coverage directly correspond to the pixels of high resolution satellite image in space. Lastly, based on the fitting relationship between vegetation coverage and the corresponding *NDVI* data derived from high resolution satellite images, the empirical models were established for estimating vegetation coverage of typical desert regions in Xinjiang. The deserts in the southern margin of the northern part of Fukang City and in the central plain of Karamay City were chosen as aerial shooting areas respectively. The relative flight height was set to 6 – 7 m and the ground resolution was 0.002 – 0.003 m. Satellite images which were shot on the same day and the day before UAV photographing, were selected and purchased for generating *NDVI* data. Agisoft Photoscan software was used for UAV image processing, ENVI and ArcGIS software packages were used for satellite remote sensing image processing and spatial analysis, Origin software was used for fitting analysis of data series and the vegetation information of UAV images was extracted by *VDVI* index. As a result, a linear model ($y = 149.86x - 13.449$, $R^2 = 0.7353$) was established for remote sensing estimation of vegetation coverage in northern sandy desert in Fukang based on *NDVI* derived from GF2 satellite image and a quadratic polynomial model ($y = 97.397x^2 + 80.837x - 5.2109$, $R^2 = 0.818$) was established for remote sensing estimation of vegetation coverage in plain desert in Karamay based on *NDVI* derived from ZY1-02C satellite image. These models might provide necessary foundation and basis for monitoring and research of land use and land cover change, ecological environment change, desertification (or sandy desertification), vegetation mapping and other related work in Xinjiang. The combination of UAV images and satellite remotely sensed data and the spatial direct correspondence between vegetation coverage statistical unit and satellite pixel, could avoid the uncertainty caused by the process of representing vegetation coverage of satellite pixel with manual measurement data at different points in the previous related work. The proposed method made the spatial matching between vegetation coverage and satellite image pixels relatively more intuitive and accurate in the process of constructing remote sensing estimation model of vegetation coverage and it also provided an idea for similar work.

Key words: *NDVI*; desert; vegetation coverage; remote sensing estimation; empirical model